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Research article

MODELING AND SIMULATION OF MOBILE BACTERIA INFLUENCED BY HETEROGENEOUS PERMEABILITY AND VOID RATIO IN FINE SAND FORMATION AT RUMUOKORO DISTRICTS OF PORT HARCOURT METROPOLIS, NIGER DELTA OF NIGERIA

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Abstract

The movement of bacterial in the soil and water environment were found to influences on heterogeneous permeability and void ratio in some part of the study area, high deposition of bacterial were found predominant in the study area causing lots of ill health, but eradication of these pollutant in soil and water environment were not carried out from risk investigation for those contaminants, base on these conditions modeling and simulation were found appropriate to solve the increasing rate of theses contaminant in soil and water environments, formulation of the system generated governing equation for the study, the derived expression generated model that will monitor the movement of bacterial in those yield aquifers, the simulation results expressed several rate of concentration at different conditions influenced by formation characteristics and deposited minerals. The theoretical values were compared with experimental values, both parameters compare faviourably well expressing the validation of the model. Experts will definitely fine these conceptual frameworks appropriate in monitoring and evaluation of contaminant in the study area.

Keywords: modeling mobile bacterial heterogeneous permeability and void ratio, fine sand formation

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1. Introduction

Uniformity of stratum is base on geologic history and geomorphology, including the geochemistry that influences the constituent of the formation, the characteristics determines the rate of microbial migration to ground water aquifers. Rivers State treasure base of the nation' is situated about 60 km from the open sea lies between longitude 6o55'E to 7o10'E of the Greenwich meridian and latitude 4o38'N to 4o54'N of the Equator, covering a total distance of about 804 km2 (Akpokodje 2001). In terms of drainage, the area is situated on the top of Bonny River and is entirely lowland with an average elevation of about 15m above sea level (Nwankwoala, 2005). The topography is under persuading of tides which a consequence is flooding especially during rainy season (Nwankwoala and Mmom, 2007, Eluozo, 2013). Climatically, the city is situated within the sub-equatorial region with the tropical monsoon weather characterized by high temperatures, low pressure and high relative dampness all the year round. The mean annual temperature, rainfall and relative dampness are 30oC, 2,300 mm and 90% correspondingly (Ashton-Jones, 1998). The soil in the area is mainly silty-clay with interaction of sand and gravel while the vegetation is an amalgamation of mangrove swamp forest and rainforest (Teme, 2002,Eluozo 2013). Rivers state falls within the Niger Delta Basin of Southern Nigeria which is defined geologically by three sub-surface sedimentary facies: Akata, Agbada and Benin formations (Whiteman, 1982). The Benin Formation (Oligocene to Recent) is the aquiferous formation in the study area with an average thickness of about 2100m at the centre of the basin and consists of coarse to medium grained sandstone, gravels and clay with an average thickness of about 2100m at the centre of the basin and consists of coarse to medium grained sandstone, gravels and clay (Etu-Efeotor and Akpokodje, 1990). The Agbada Formation consists of alternating deltaic (fluvial coastal, fluviomarine) and shale, while Akata Formation is the basal sedimentary unit of the entire Niger Delta, consisting of low density, high pressure shallow marine to deep water shale (Schield, 1978). The quantity and quality of ground water resources of any region are restricted by the climate and geology of the area. The climate through rainfall and surface water resources ensure steady supply or recharge to groundwater resources of an area in a complex hydrological cycle. The geology of the region determines the aquiferous zones where exploitable groundwater may occur and influences the geochemical Characteristics of the groundwater, amongst other factors such as human activities (Domenico, 1972). The geochemical characteristics of the groundwater in turn influence the quality of the groundwater resources. Earlier works by Demenico, and Schwartz (1998), Ahiarakwem and Ejimadu (2002), Downey (1984), Aniya and, Schoenekeck K (1992), Idowu et al. (1999) and Awalla and Ezeigbo (2002) have confirmed the influence of local geology on the aquifer characteristics and quality of groundwater resources of any area. Human activities may also influence the quality of groundwater in the region (Alagbe, 2006). Groundwater has been described as the main source of potable water supply for domestic, industrial and agricultural uses in the southern part of Nigeria especially the Niger Delta, due to long retention time and natural filtration capacity of aquifers (Odukoya et al., 2002; Agbalagba et al., 2011; Ehirim and Ofor, 2011). Water that is safe for drinking, pleasant in taste, and suitable for domestic purposes is designated as potable water and must not contain any chemical or biological impurity (Horsfall and Spiff, 1998). Pollution of groundwater has gradually been on the increase especially in our cities with lots of industrial activities, population growth, poor sanitation, land use for commercial agriculture and other factors responsible for environmental degradation (Egila and Terhemen, 2004). The concentration of contaminants in the groundwater also depends on the level and type of elements introduced to it naturally or by human activities and distributed through the geological stratification of the area. It has been reported that petroleum refining contributes solid, liquid, and gaseous wastes in the environment (Ogbuagu, et al., 2011). Some of these wastes could contain toxic components such as the polynuclear aromatic hydrocarbons (PAHs), which have been reported to be the real contaminants of oil and most abundant of the main hydrocarbons found in the crude oil mixture (El-Deeb and Emara, 2005). Once introduced in the environment, PAHs could be stable for as short as 48 hours (e.g. naphthalene) or as long as 400 days (e.g. fluoranthene) in soils (Martens and Frankenberger, 1995). They thus, resist degradation and, remain persistent in sediments and when in organisms, could accumulate in adipose tissues and further transferred up the trophic chain or web (Decker, 1981; Schwartz, 2003 Boehm et al., 1981).

2. Governing equation

$$V\frac{\partial Cs}{\partial t} = D_s\frac{\partial Cs}{\partial z}$$

We approach this system using the Bernoulli's method of separation of variables.

i.e. $Cs_2 = ZT$ ……………… (2)

$$\frac{\partial Cs_2}{\partial t} = ZT^1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\frac{\partial Cs_2}{\partial z} = Z^1T \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Put (3) and (4) into (2), so that we have

$$VZT^1 = qzCs\ Z^1T \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$VZT^1\frac{VT^1}{T} = qzCs\frac{Z^1}{Z} = -\lambda^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Hence $\frac{VT^1}{T} = -\lambda^2$ ……………… (7)

$$qzCs\,Z^1 + \lambda^2 Z = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

From (8) $T = ACos\frac{\lambda t}{V} + B\ Sin\frac{\lambda z}{V}$ ……………… (9)

And (8) gives $T = \frac{-\lambda^2}{Cs\ell^v}t + B\ Sin\frac{\lambda z}{V}$ ……………… (10)

By substituting (8) and (9) into (2)

$$Cs_2 = \left[ACos\frac{\lambda}{\sqrt{V}}t + B\,Sin\frac{\lambda}{\sqrt{V}}x\right]Cs\ell^{\frac{-\lambda^2}{\sqrt{V}}t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$Cs_o = Ac \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Equation (2) derived by direct integration of some parameters was in accordance with the system, directed integration were found necessary to couple the variables they have similarity ,this is base on the deposition of the ammonia reflecting the concentration of the microbes from organic soil, it is confirmed that the concentration of ammonia and Klebsiella experience high degree of concentration. Variable were found to express their relation with each other in terms of their influences of increase include deposition of ammonia increase in microbial inhabitants in organic soil, the accumulations of ammonia are very high.

Equation (11) becomes

$$Cs_2 = Cs_o \ell \frac{-\lambda^2}{Ds} t \; Cos \frac{\lambda}{V} x \quad \ldots\ldots\ldots\ldots \quad (13)$$

Again at $\left.\frac{\partial Cs_2}{\partial t}\right| \begin{matrix} = 0, \; x = 0 \\ t = 0, \; B \end{matrix}$

Equation (13) becomes

$$\frac{\partial Cs_2}{\partial t} = \frac{\lambda}{V} Cs_o \ell^{\frac{-\lambda^2}{Ds}t} \; Sin \frac{\lambda}{V} x \quad \ldots\ldots\ldots\ldots \quad (14)$$

i.e. $0 = \frac{\lambda}{\sqrt{V}} \; Sin \frac{\lambda}{V} 0 \quad \ldots\ldots\ldots\ldots \quad (15)$

$Cs_o \frac{\lambda}{\sqrt{V}} \neq 0$ Considering NKP

$$0 = -Cs_o \frac{\lambda}{V} \; Sin \frac{\lambda}{V} B \quad \ldots\ldots\ldots\ldots \quad (16)$$

$$\lambda = \frac{n\pi\sqrt{V}}{2} \quad \ldots\ldots\ldots\ldots \quad (17)$$

So that equation (30) becomes

$$Cs_2 = Cs_o \ell^{\frac{-n^2\pi^2 V}{2Ds}} \; Cos \frac{n\pi\sqrt{V}}{2\sqrt{V}} x \quad \ldots\ldots\ldots\ldots \quad (18)$$

$$Cs_2 = Cs_o \ell^{\frac{-n^2\pi^2 V}{2Ds}} \; Cos \frac{n\pi}{2} x \quad \ldots\ldots\ldots\ldots \quad (19)$$

2. Materials and method

Soil samples from several different borehole locations, were collected at intervals of three metres each (3m). Soil sample were collected in five different location, applying insitu method of sample collection, the soil sample were collect for analysis, standard laboratory analysis were collected to determine the soil formation, the result were analysed to determine the rate of bacterial concentration between coarse formation through column experiment in the study area.

3. Results and Discussion

Theoretical and experimental values from every condition on the developed model are expressed in figures and tables below.

Table: 1 concentration of the bacterial at Different Depths

Depths [M]	Concentration [Mg/l]
3	1.25E-10
6	5.02E-10
9	1.13E-09
12	2.01E-09
15	3.14E-09
18	4.52E-09
21	6.15E-09
24	8.04E-09
27	1.01E-08
30	1.25E-08

Table: 2 concentration of the bacterial at Different Time

Time [Days]	Concentration [Mg/l]
10	1.25E-10
20	5.02E-10
30	1.13E-09
40	2.01E-09
50	3.14E-09
60	4.52E-09
70	6.15E-09
80	8.04E-09
90	1.01E-08
100	1.25E-08

Table: 3 and 4 Comparison of theoretical and experimental values of bacterial at Different Depths and Time

Depths [M]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
3	1.25E-10	1.29E-10
6	5.02E-10	5.44E-10
9	1.13E-09	1.21E-09
12	2.01E-09	2.34E-09
15	3.14E-09	3.56E-09
18	4.52E-09	4.88E-09
21	6.15E-09	6.88E-09
24	8.04E-09	8.45E-09
27	1.01E-08	1.32E-08
30	1.25E-08	1.44E-08

Time [Days]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
10	1.25E-10	1.29E-10
20	5.02E-10	5.44E-10
30	1.13E-09	1.21E-09
40	2.01E-09	2.34E-09
50	3.14E-09	3.56E-09
60	4.52E-09	4.88E-09
70	6.15E-09	6.88E-09
80	8.04E-09	8.45E-09
90	1.01E-08	1.32E-08
100	1.25E-08	1.44E-08

Table: 5 concentration of the bacterial at Different Depths

Depths [M]	Concentration [Mg/l]
3	1.49E-03
6	2.99E-03
9	4.49E-03
12	5.99E-03
15	7.49E-03
18	8.99E-03
21	1.00E-02
24	1.20E-02
27	1.30E-02
30	1.50E-02

Table: 6 Comparison of theoretical and experimental values of bacterial at Different Depths

Depths [M]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
3	1.49E-03	1.51E-03
6	2.99E-03	3.11E-03
9	4.49E-03	4.67E-03
12	5.99E-03	5.64E-03
15	7.49E-03	7.56E-03
18	8.99E-03	8.51E-03
21	1.00E-02	1.24E-02
24	1.20E-02	1.24E-02
27	1.30E-02	1.44E-02
30	1.50E-02	1.55E-02

Table: 7 Comparison of Theoretical and experimental values of bacterial at Different Time

Time [Days]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
10	1.49E-03	1.51E-03
20	2.99E-03	3.11E-03
30	4.49E-03	4.67E-03
40	5.99E-03	5.64E-03
50	7.49E-03	7.56E-03
60	8.99E-03	8.51E-03
70	1.00E-02	1.24E-02
80	1.20E-02	1.24E-02
90	1.30E-02	1.44E-02
100	1.50E-02	1.55E-02

Table: 8 concentration of the bacterial at Different Time

Time [Days]	Concentration [Mg/l]
10	1.49E-03
20	2.99E-03
30	4.49E-03
40	5.99E-03
50	7.49E-03
60	8.99E-03
70	1.00E-02
80	1.20E-02
90	1.30E-02
100	1.50E-02

Table: 9 concentration of the bacterial at Different Depths

Depths [M]	Concentration [Mg/l]
3	1.25E-09
6	5.03E-14
9	1.49E-13
12	1.34E-12
15	3.05E-12
18	4.52E-13
21	7.81E-13
24	8.04E-13
27	1.01E-12
30	1.59E-13

Table: 10 concentration of the bacterial at Different Time

Time [Days]	Concentration [Mg/l]
10	1.25E-09
20	5.03E-14
30	1.49E-13
40	1.34E-12
50	3.05E-12
60	4.52E-13
70	7.81E-13
80	8.04E-13
90	1.01E-12
100	1.59E-13

Table: 11 Comparison of Theoretical and experimental values of bacterial at Different Depths

Depths [M]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
3	1.25E-09	1.31E-09
6	5.03E-14	5.44E-14
9	1.49E-13	1.53E-13
12	1.34E-12	1.44E-12
15	3.05E-12	3.15E-12
18	4.52E-13	4.66E-13
21	7.81E-13	7.66E-13
24	8.04E-13	8.11E-13
27	1.01E-12	1.12E-12
30	1.59E-13	1.66E-13

Table: 12 Comparison of Theoretical and experimental values of bacterial at Different Time

Time [Days]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
10	1.25E-09	1.31E-09
20	5.03E-14	5.44E-14
30	1.49E-13	1.53E-13
40	1.34E-12	1.44E-12
50	3.05E-12	3.15E-12
60	4.52E-13	4.66E-13
70	7.81E-13	7.66E-13
80	8.04E-13	8.11E-13
90	1.01E-12	1.12E-12
100	1.59E-13	1.66E-13

Table: 13 concentration of the bacterial at Different Depths

Depths [M]	Concentration [Mg/l]
3	2.09E-04
6	4.19E-04
9	6.29E-04
12	8.39E-04
15	1.04E-03
18	1.25E-03
21	1.46E-03
24	1.67E-03
27	1.88E-03
30	2.09E-03

Table: 14 concentration of the bacterial at Different Time

Time [Days]	Concentration [Mg/l]
10	2.09E-04
20	4.19E-04
30	6.29E-04
40	8.39E-04
50	1.04E-03
60	1.25E-03
70	1.46E-03
80	1.67E-03
90	1.88E-03
100	2.09E-03

Table: 15 Comparison of Theoretical and experimental values of bacterial at Different Depths

Depths [M]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
3	2.09E-04	2.11E-04
6	4.19E-04	4.33E-04
9	6.29E-04	6.11E-04
12	8.39E-04	8.54E-04
15	1.04E-03	1.11E-03
18	1.25E-03	1.31E-03
21	1.46E-03	1.43E-03
24	1.67E-03	1.67E-03
27	1.88E-03	1.78E-03
30	2.09E-03	2.14E-03

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Table: 16 Comparison of Theoretical and experimental values of bacterial at Different Time

Time [Days]	Theoretical values [Mg/l]	Experimental Values [Mg/L]
10	2.09E-04	2.11E-04
20	4.19E-04	4.33E-04
30	6.29E-04	6.11E-04
40	8.39E-04	8.54E-04
50	1.04E-03	1.11E-03
60	1.25E-03	1.31E-03
70	1.46E-03	1.43E-03
80	1.67E-03	1.67E-03
90	1.88E-03	1.78E-03
100	2.09E-03	2.14E-03

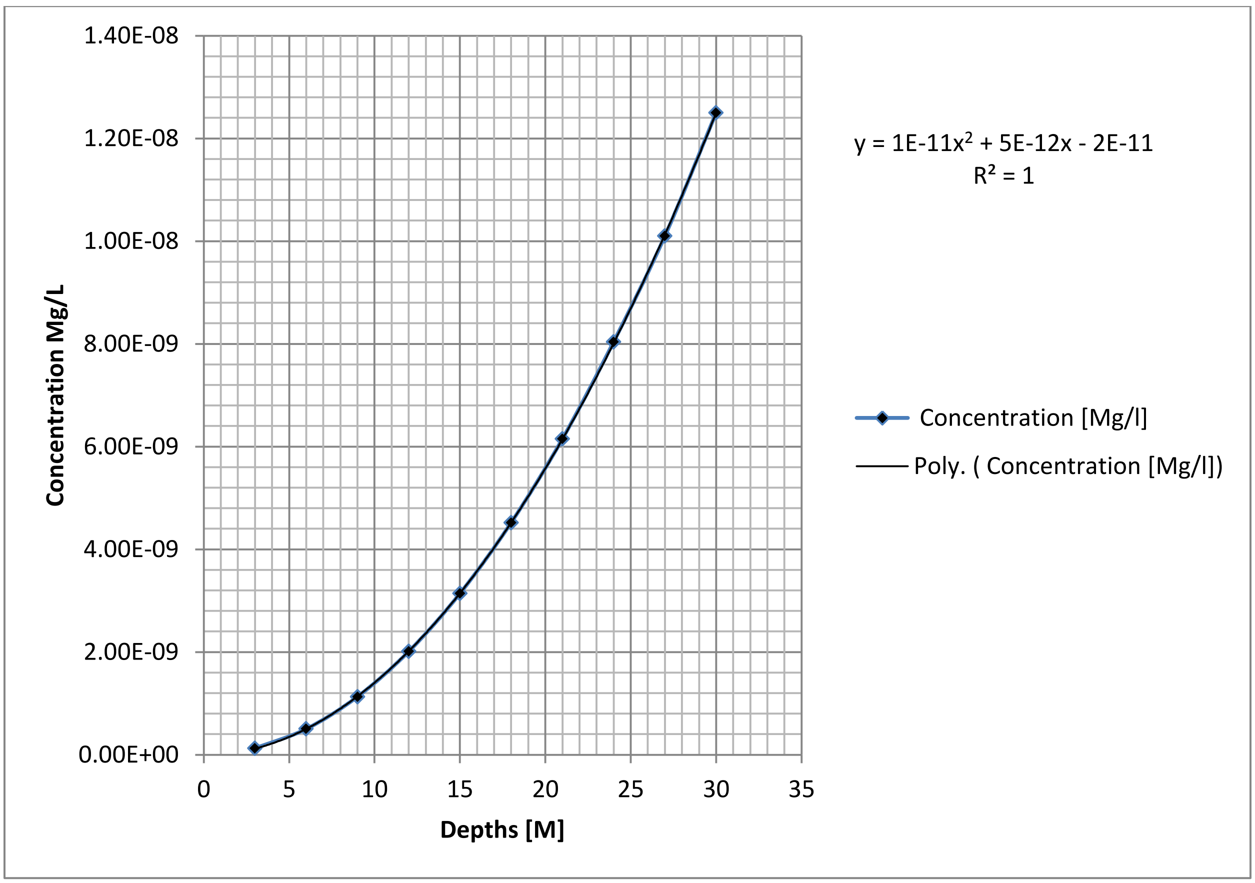

Figure: 1 concentration of the bacterial at Different depths

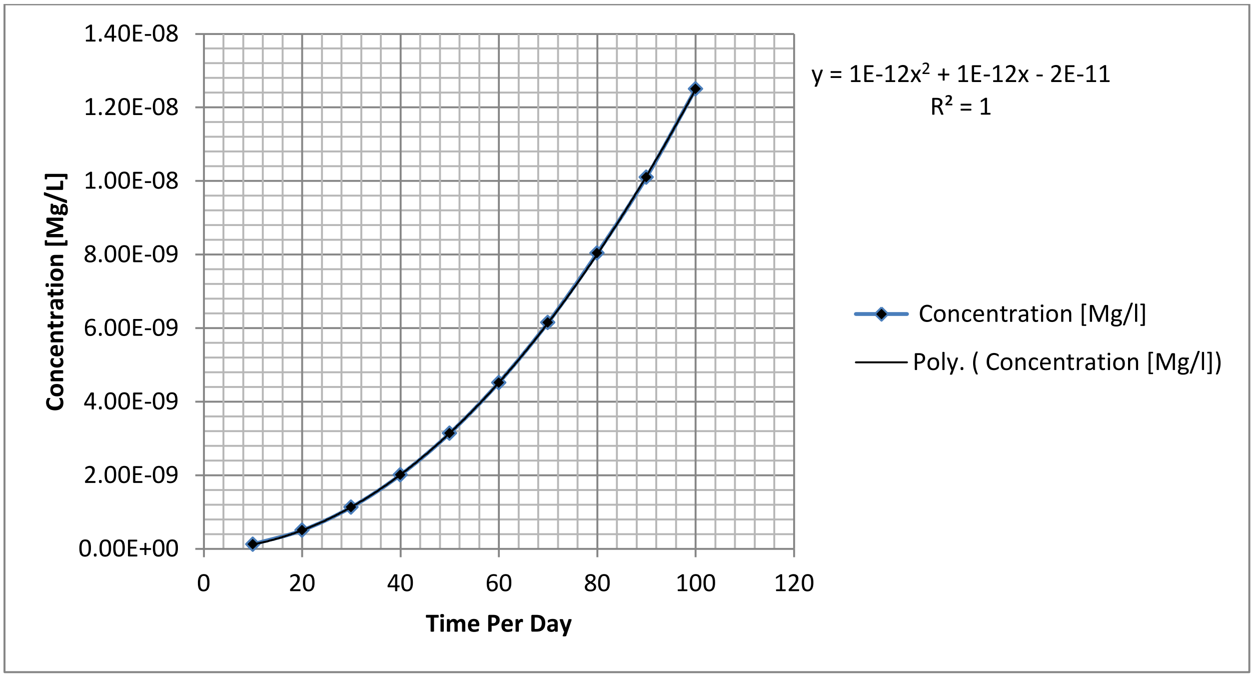

Figure: 2 concentration of the bacterial at Different Time

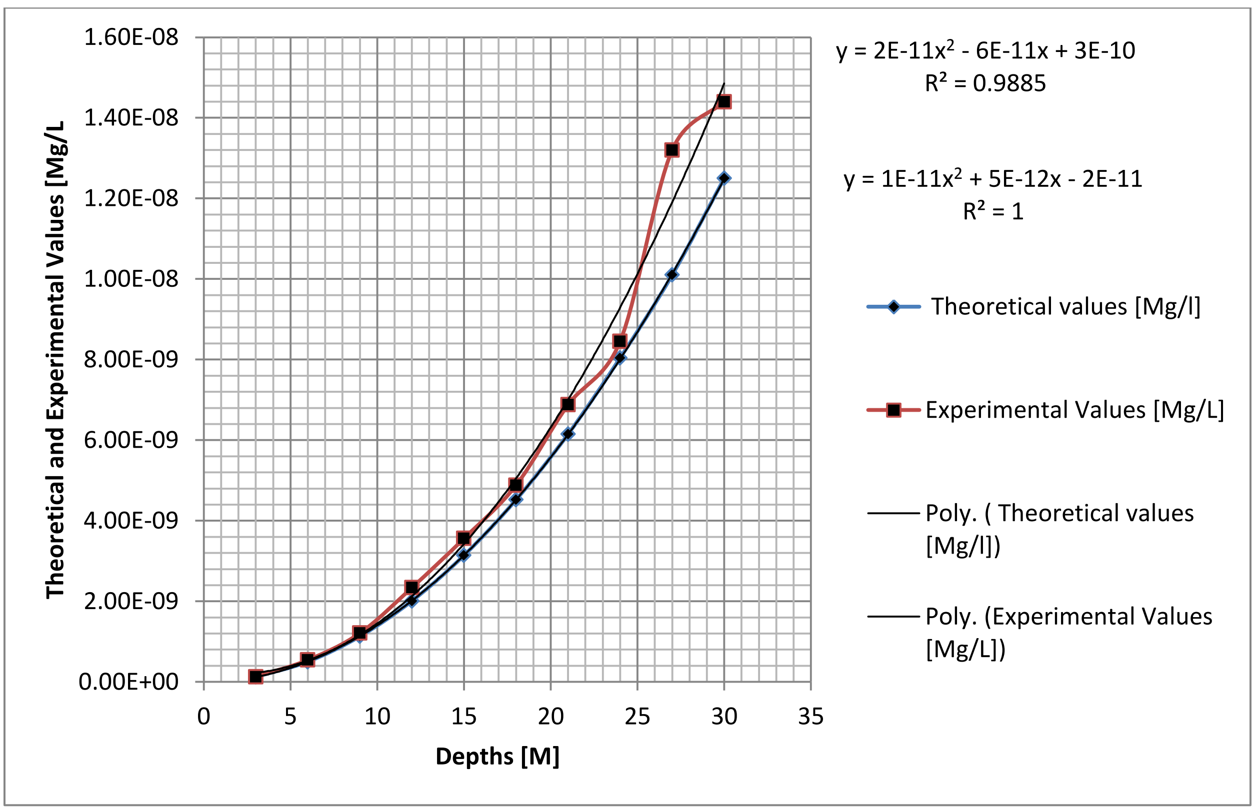

Figure: 3 Comparison of Theoretical and experimental values of bacterial at Different Depths

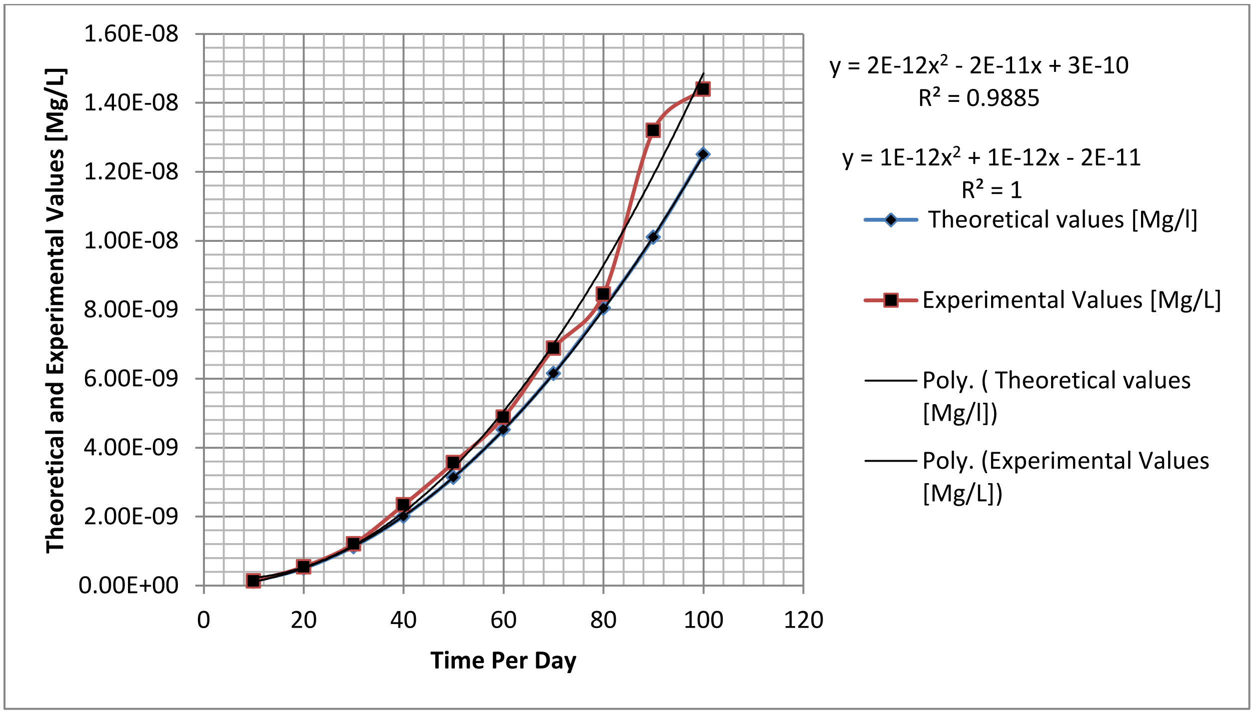

Figure: 4 Comparison of Theoretical and experimental values of bacterial at Different Time

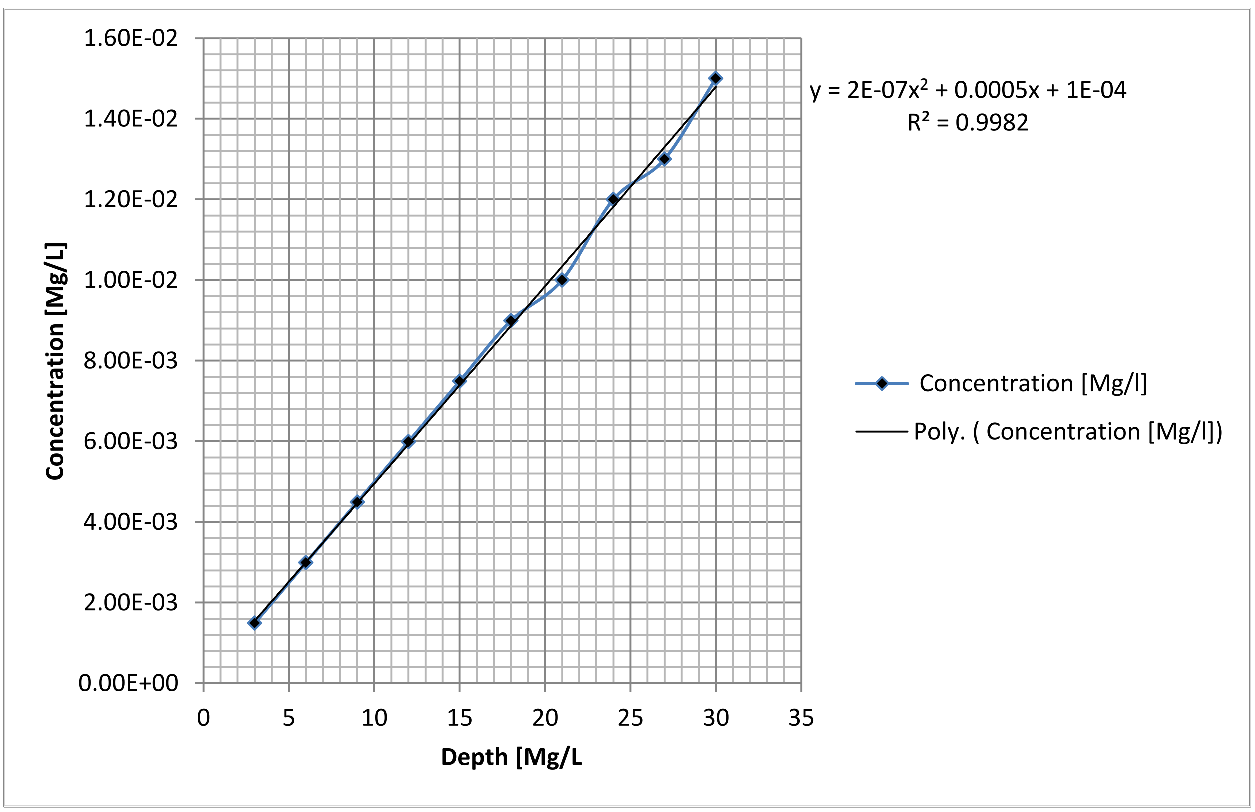

Figure: 5 concentration of the bacterial at Different Depths

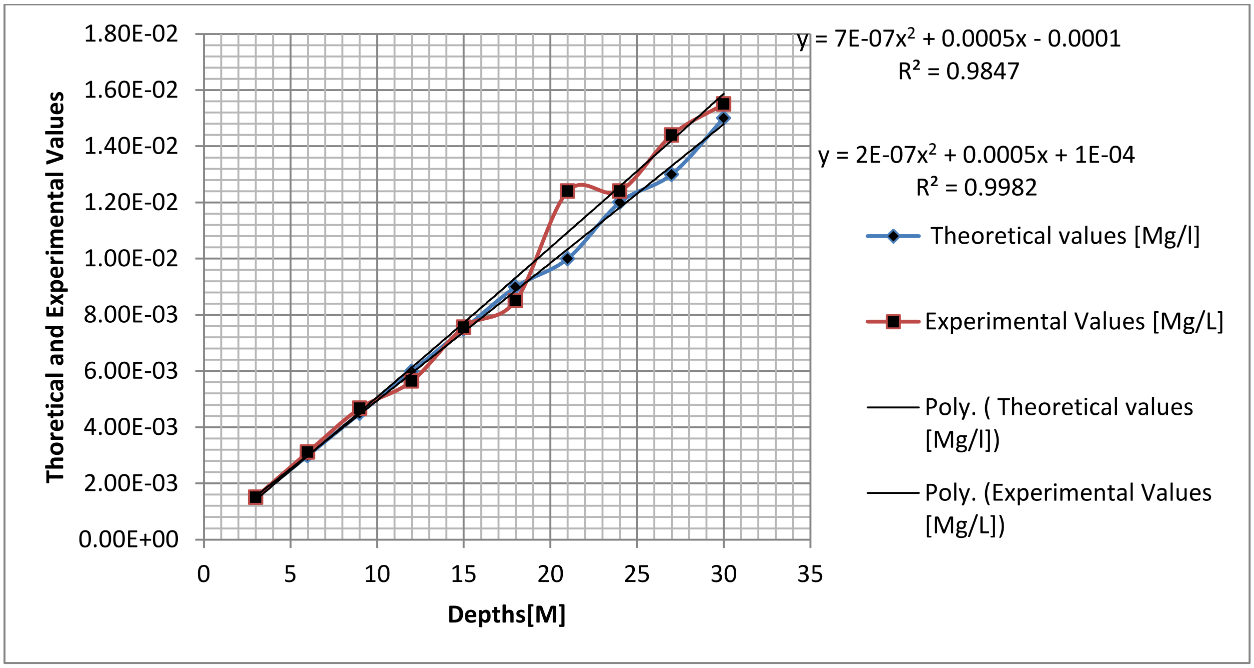

Figure: 6 Comparison of Theoretical and experimental values of bacterial at Different Depths

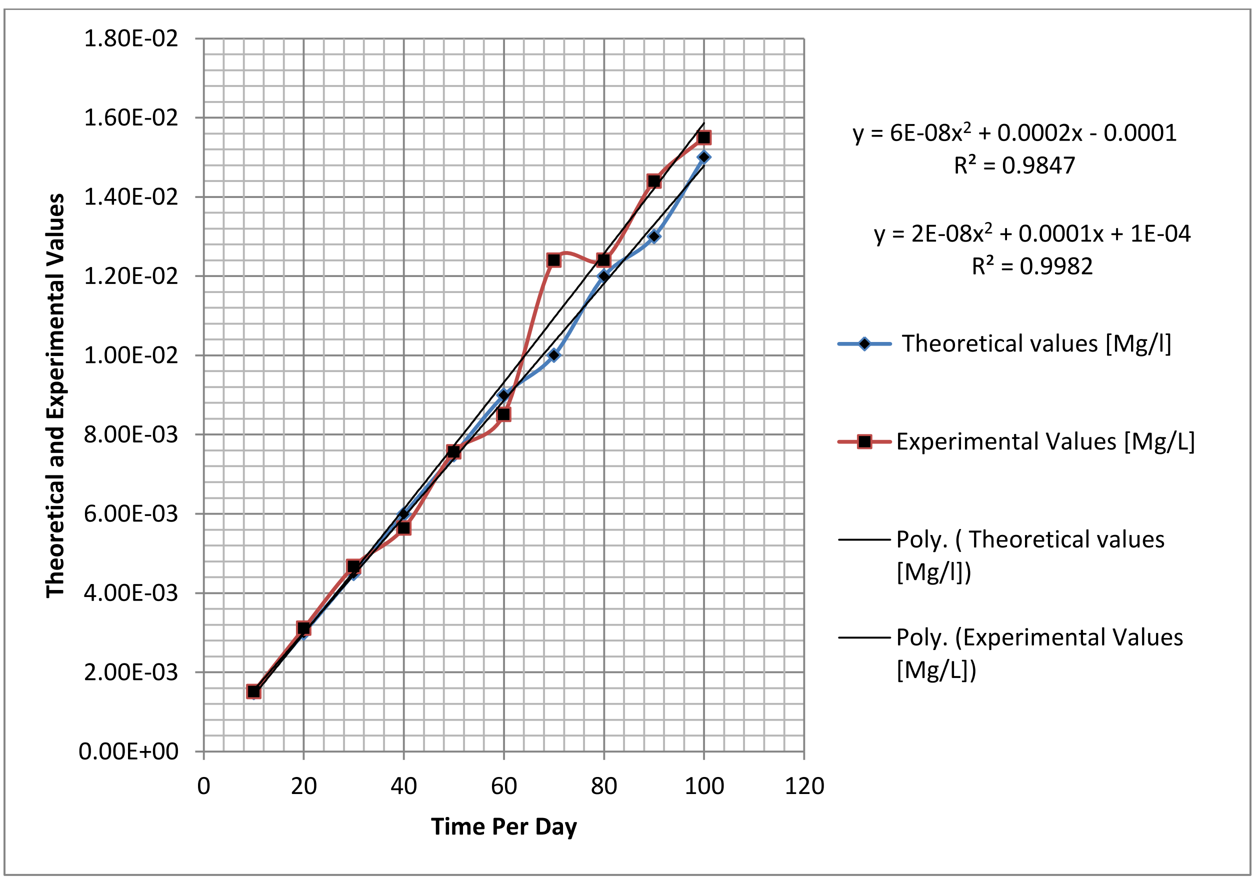

Figure: 7 Comparison of Theoretical and experimental values of bacterial at Different Time

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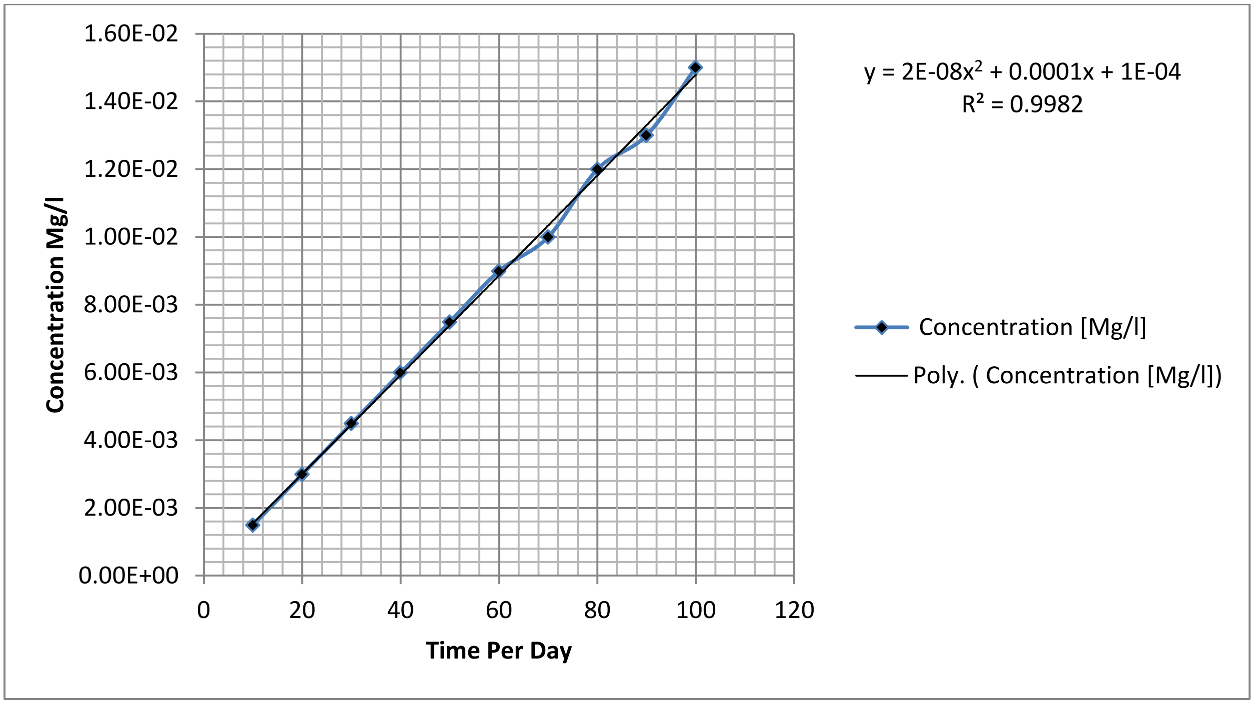

Figure: 8 concentration of the bacterial at Different Time

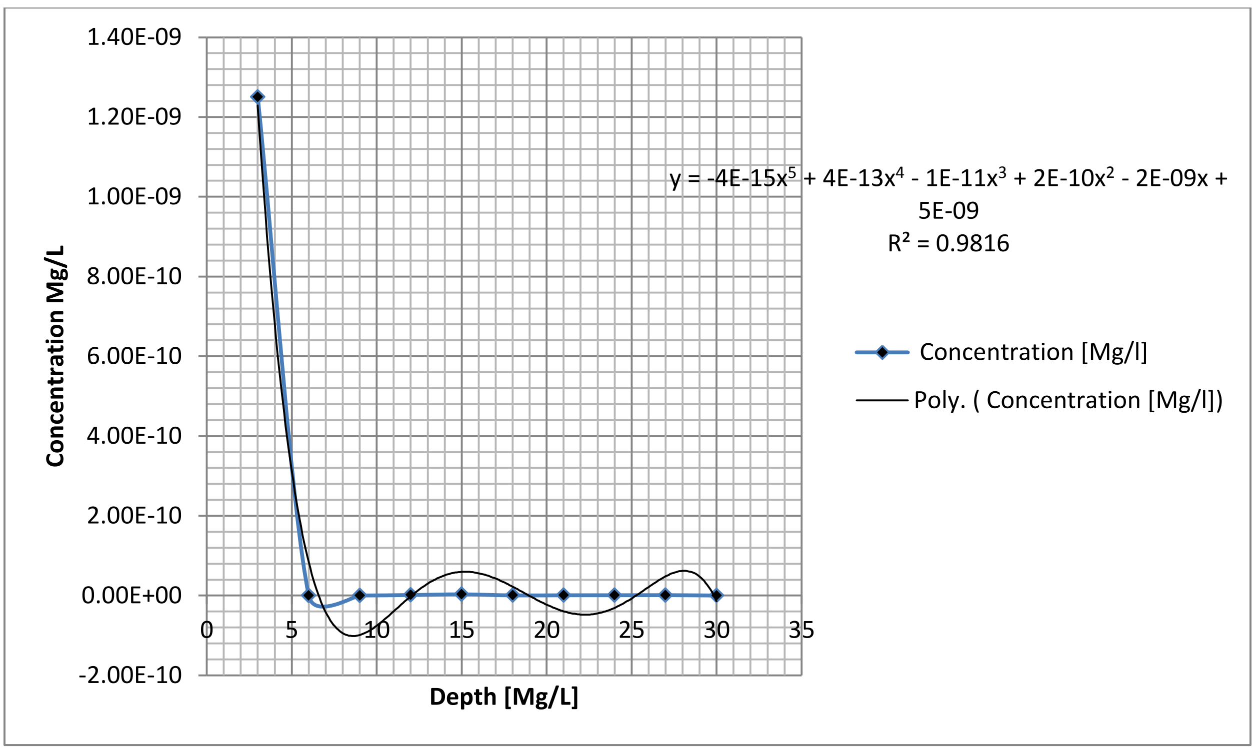

Figure: 9 concentration of the bacterial at Different Depths

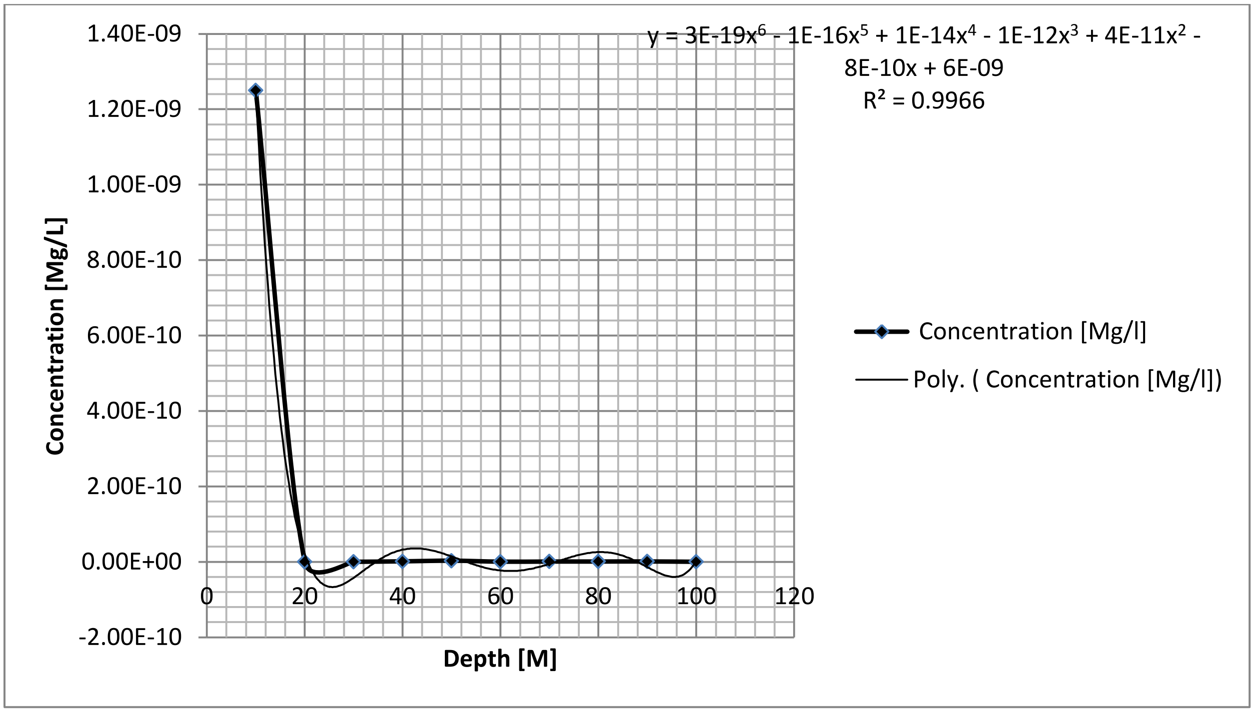

Figure: 10 concentration of the bacterial at Different Depths

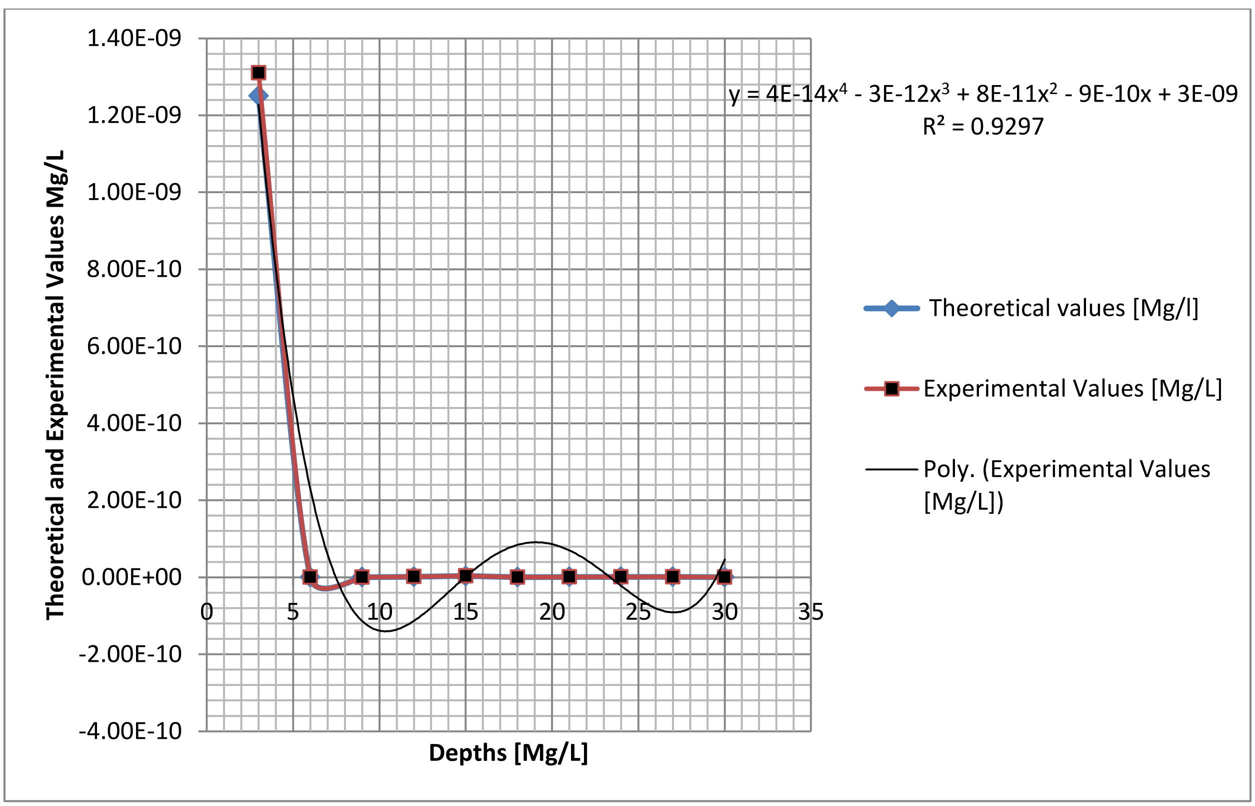

Figure: 11 Comparison of Theoretical and experimental values of bacterial at Different Time

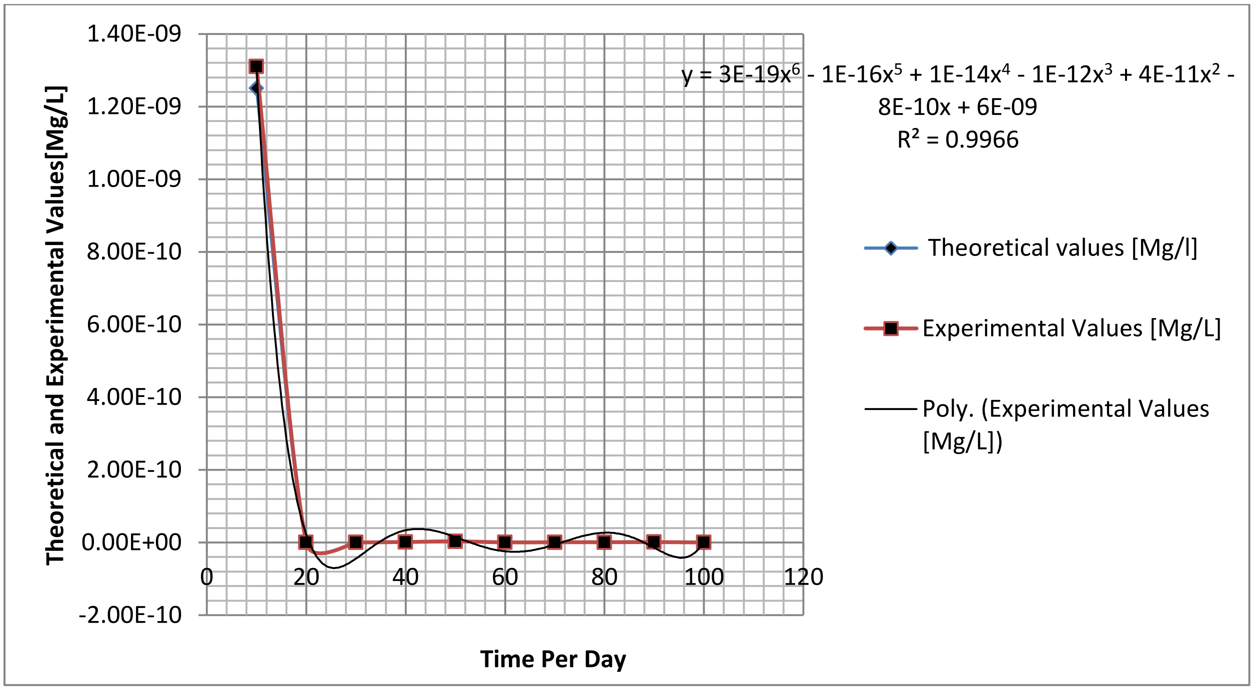

Figure: 12 Comparison of Theoretical and experimental values of bacterial at Different Time

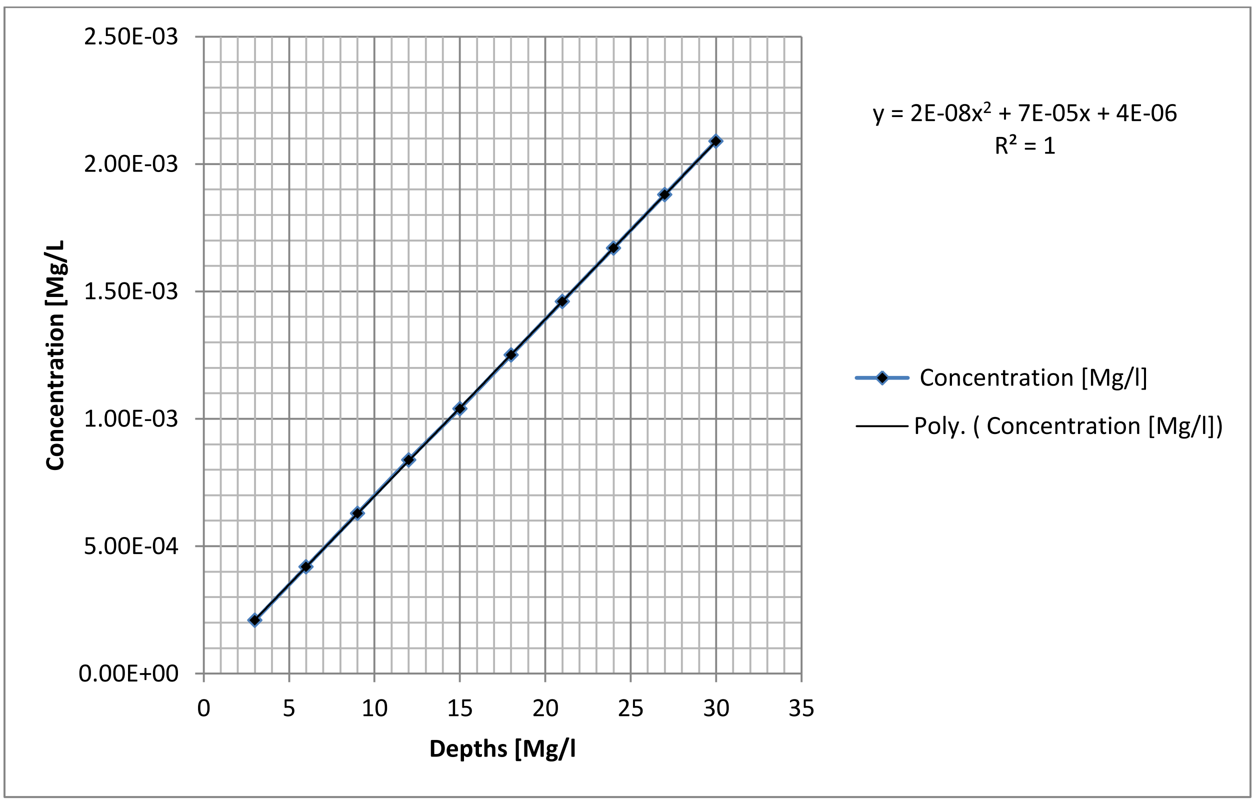

Figure: 13 concentration of the bacterial at Different Depths

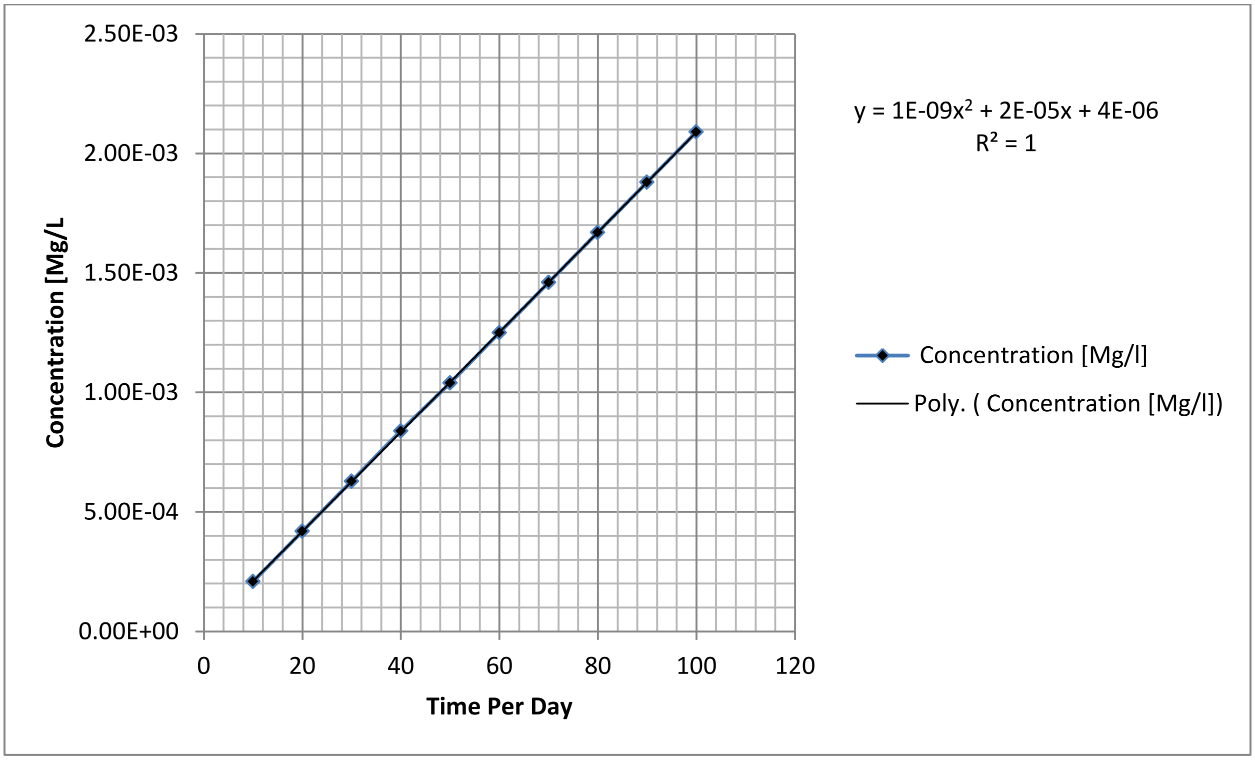

Figure: 14 concentration of the bacterial at Different Time

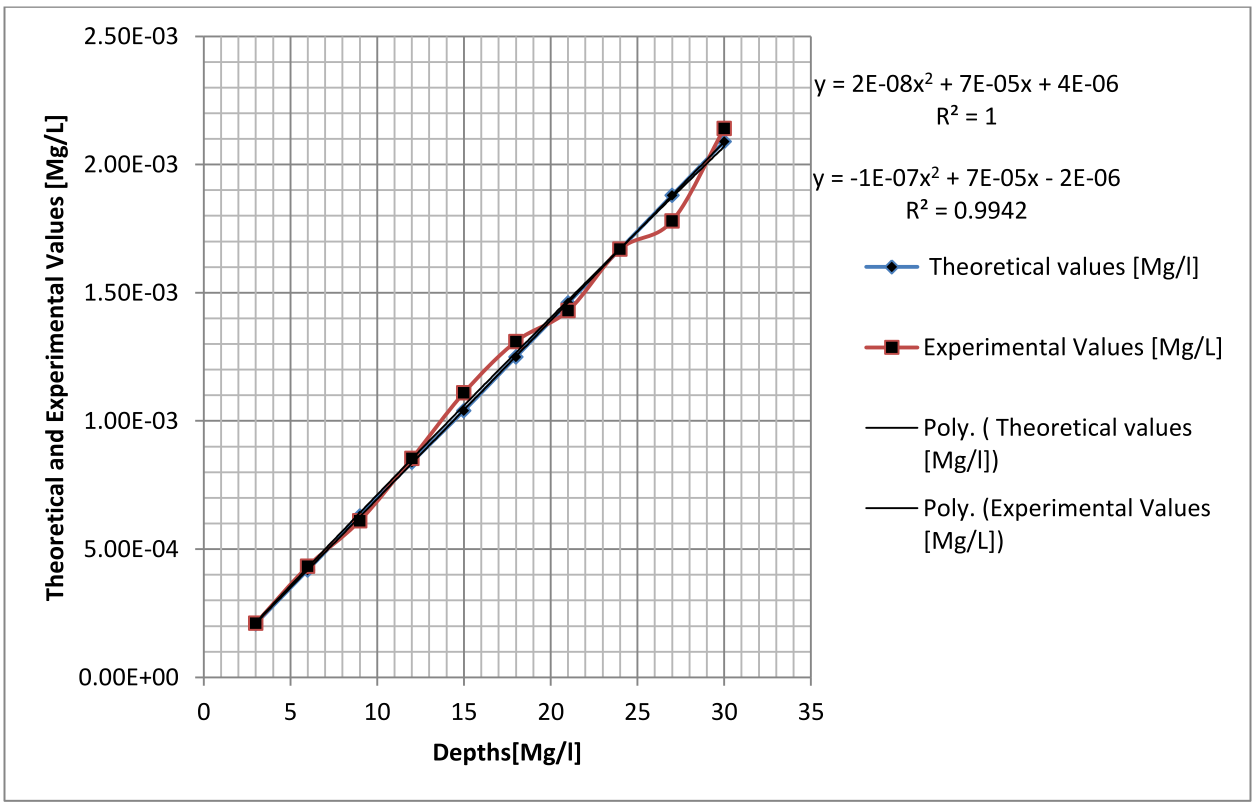

Figure: 15 Comparison of Theoretical and experimental values of bacterial at Different Depths

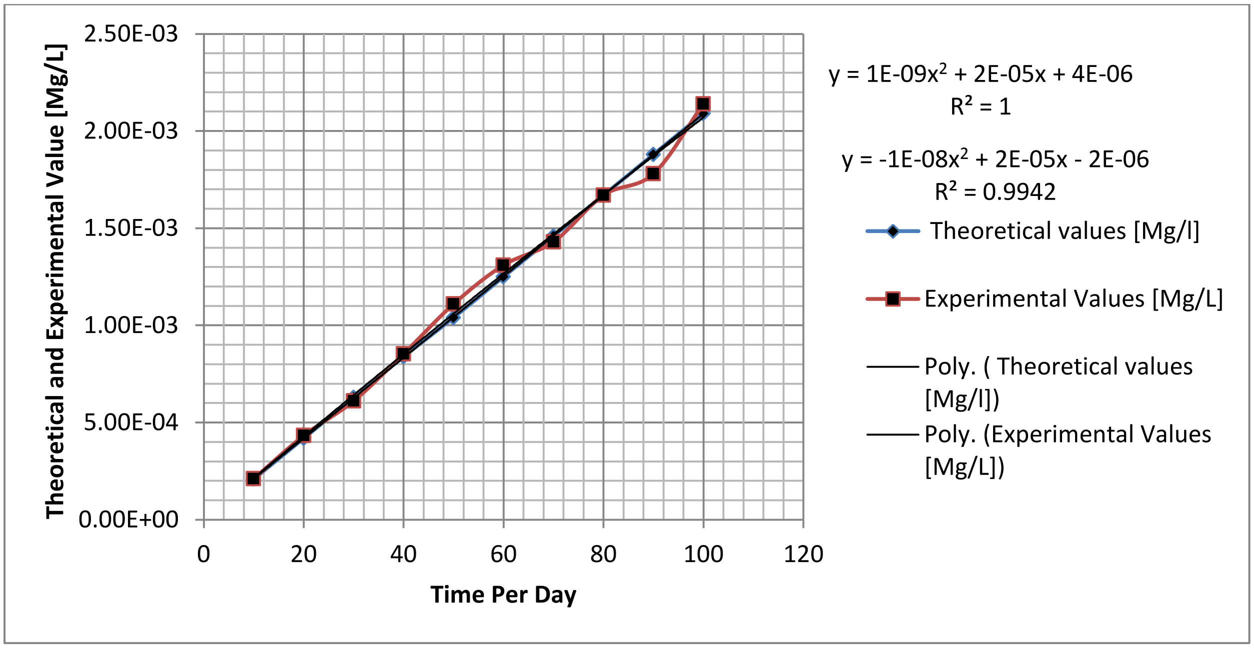

Figure: 16 Comparison of Theoretical and experimental values of bacterial at Different Time

Figures one to four shows that the bacterial were increasing with increase in depths under the influences of high percentage of microbes in formation, substrate utilization were found in some region of the strata, this developed increase in population of the microbes, slight decline in concentration were experienced in the aquiferous zone, these can be attributed to minor decrease of permeability within the yield zone, but may be insignificants in the transport system at those locations. The migration of bacteria were observed to migration in gradual process as it is expressed in figures one to four, the concentration developed minor variation due to slight heterogeneous strata observed in the study area, while figures five to eight experienced different behaviour from one to four, the microbes were observed under exponential condition , this can be attributed to decline in permeability and void ratio at those region formation expressed in the figures , the migration of bacteria were influenced by the rate of permeability observed to experienced slight degradation, figures nine to twelve expressed high to low concentration, the system were influenced by inhibition of the microbes by some deposited minerals, substrate were in active in those formation as it is expressed from the figures, these figures decrease in concentration base on these stated influences from the system, such condition determine the quality of aquiferous zone in those locations. Figures thirteen to sixteen express higher concentration at exponential phase, the migration were observed to rapidly increase due the deposition of microelements in the strata, it increase the microbial population and the deposition of permeability were very high, this condition develop high concentration of microbes as it expressed in the figures. The rate of concentration are determine by lots of influences from formation characteristics and deposited minerals in the formations, the developed model generated theoretical values, these results were compare with experimental values, both parameters generated a best fits expressing validation of the model, several condition were considered in the system thus from the behaviour and formation variation influences on the transport process, the expressed model were simulated at different condition considered on the developed model, such condition were found to reflect on the transport process observed from all the presented figures, this can be applied to understand the rate of contaminant at every formation in the study area.

5. Conclusion

The deposition of mobile bacterial at homogeneous permeability and void ratio has been mathematically expressed, the expression were from the rate of bacterial concentration observed from risk assessment investigation carried out shows the rate of pollution in the formation to aquiferous zone. Such results were to determine the cause of ground water pollution sources in the study area, but permanent solution to prevent further migration were not done, high rate of these contaminant continue to pollute the formation generating high rate of water contamination, this condition has developed rapid rate of water related diseases in the study location causing high rate of death, subject to this ugly scourge, mathematical model were found suitable to thoroughly express the rate of bacterial migration at strata that yield aquifers in the study location, the study were establish to express various rate of concentration within the aquiferous zone, several rate of influences were observed, but the paramount parameter were permeability and void ratio, theses two parameters were predominantly high reflecting on the concentration and migration of the microbes. Simulated values were d with experimental results, both parameters developed a best fits expressing validation of the model.

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